Faculty of Manufacturing Engineering

THE EFFECT OF COOLING RATE ON MECHANICAL AND MORPHOLOGICAL PROPERTIES OF HEAT TREATED RECYCLED ALUMINUM ALLOY FROM SCRAP

Haji Azim B. Aziz

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HJ. AZIM BIN AZIZ

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Master Degree of Manufacturing Engineering (Manufacturing Systems Engineering)

Faculty Of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013

DECLARATION

I hereby, declared this report entitled "**The Effect Of Cooling Rate On Mechanical And Morphological Properties Of Heat Treated Recycled Aluminum Alloy From Scrap**" is the results of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Author's Name	:	Haji Azim bin Aziz
Date	:	....

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Master of Manufacturing Engineering (Manufacturing Systems Engineering). The members of supervisory committee are as follow:

....

DR. NORAIHAM BINTI MOHAMAD
Lecturer
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka

....

ABSTRACT

Aluminum is the most widely used metal in the world of engineering apart from iron due to the combination of mechanical properties making it one of the most versatile of engineering and construction materials, and recycling is one of the best solution to the disposing of the tons of wastes and residue due to spoilt or end of products life. In order to use the recycled material to be turned back into the same product or better, something has to be done to enhance or improve the mechanical properties of the material. The purpose of this study is to investigate the effect of cooling rates on the mechanical and morphological properties of heat treated recycled automotive aluminum alloy scraps where they were first sorted according to a determined classification and were melted and casted, machined to sample size and undergo heat treatment. The samples were then cooled using four different medium, quenched (used engine oil, water and air from fan) or annealed (left in the oven to slowly cool down to room temperature). Cooling rates for each medium were recorded at intervals and plotted as time vs temperature graph. Characterization on samples before scrap melting, after casted and after cooling process, shows occurence of morphological changes confirming the hypothesis that cooling rates affect the microstructure of the metals being better and finer. Faster cooling rates generated finer grains and uniform distribution of silicon particles. The samples were further tested for impact strength and tensile properties through an izod pendulum impact tester and a universal testing machine. It can be concluded that increasing cooling rate increases the capability of metal to withstand impact of o.8 J/mm but decreases the tensile stress, strain and modulus E.

ABSTRAK

Aluminum adalah logam yang paling banyak digunakan dalam dunia kejuruteraan selain daripada besi kerana gabungan sifat mekanikal menjadikan ia salah satu bahan kejuruteraan dan pembinaan yang paling versatil, dan kitar semula merupakan salah satu satunya penyelesaian terbaik kepada pelupusan sisa pejal tersebut. Bagi membolehkan bahan yang telah dikitar tersebut dapat digunakan semula untuk menghasilkan komponen yang sama atau lebih baik, sesuatu mestilah dilakukan untuk menambahbaik atau mengembalikannya ke sifat asal. Tujuan kajian ini adalah untuk menyiasat kesan kadar penyejukkan ke atas sifat mekanikal dan morfologikal bahan sisa aluminum yang telah dikitar semula dan dibuat rawatan haba ke atasnya dimana aluminum akan diasingkan mengikut klasifikasi yang ditentukan dan dilebur, dituang dan kemudiannya dimesin menjadi sampel dan dibuat rawatan haba.. Sampel disejukkan menggunakan empat media, direndam (minyak enjin yang telah digunakan, air dan dibawah kipas) atau 'annealled' iaitu penyejukkan secara semulajadi (udara suhu bilik, atau udara didalam ketuhar yang terbuka pintunya). Kadar penyejukan bagi setiap media akan direkodkan yang akan menghasilkan graf suhu kepada masa. Penentuan sifat dibuat pada permulaan sebelum dilebur, selepas dituang dan selepas penyejukkan menunjukkan berlakunya perubahan morfologikal yang mengesahkan hipotesis bahawa kadar penyejukkan mempengaruhi mikrostruktur tuangan aluminum yang dikitar semula menjadikannya lebih baik dan halus. Kadar penyejukkan yang lebih cepat menghasilkan. Kadar penyejukan lebih cepat menghasilkan butiran lebih halus dan taburan seragam zarah- zarah silikon. Sampel seterusnya diuji untuk kekuatan hentaman dan ciri-ciri tegang melalui mesin penguji hentakan pendulum izod dan satu mesin ujian universal. Ia boleh disimpulkan bahawa meningkatkan kadar penyejukan akan meningkatkan keupayaan logam menahan hentakan(0.8 J/mm) tetapi mengurangkan nilai tegasan tegangan, terikan dan modulus E.

DEDICATION

This work is dedicated to my beloved family, especially my wife without their caring support, drive and the respect for education it would not have been possible.

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LIST OF ABBREAVIATIONS

ADTEC	-	Advanced Technology Training Center
AFC	-	Aluminium Finishing Cut
Al-Si	-	Aluminum-Silicon
AMREC	-	Advanced Material Research Center
ARC	-	Aluminium Rough Cut
ASA	-	American Standard Association
ASM	-	American Society for Metals
C	-	Carbon
CCD	-	Charge Coupled Device
CNC	-	Computer numerical control
CO_2	-	Carbon dioxide
Cu	-	Copper
DIN	-	Deutch Institute for Normung (German Standard Code)
J	-	Joule
Max	-	Maximum
mm	-	milimeter
MPa	-	Mega Pascal
N	-	Newton
OM	-	Optical Microscope
SEM	-	Scanning Electron Microscope
SIRIM	-	Standards & Industrial Research Institute of Malaysia Berhad
wt	-	weight
XRD	-	X-Ray Device

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CHAPTER 1

INTRODUCTION

1.1 Recycling work of aluminum alloys and why it is important

Aluminum alloy has a vast number of types that is being continuously researched and produced by industries to accommodate the variety of application and usage ranging from household products to space equipments calling for the needs of mining and producing more materials to cater and supply the rising demands. And due to the high consumption of the various aluminum based products, the earth may one day become exhausted of the mineral causing a breakdown in the aluminum based industries. Logically because of the high consumption rate of aluminum based products in the world, there will definitely be a lot of spoilt, broken or unusable products thrown away as wastes. These wastes will surely pose a problem for the local authority and council to dispose of the waste materials without causing any side effect on the environment. Aluminum is known to react with oxygen causing oxidation creating toxic and causing harmful effect on the surrounding environments. A lot of Studies has been made and it is found that aluminum is the third most abundant element on earth after oxygen and silicon and have been ingested almost every day by human. Due to the abundance existence of the material in the environment, human exposure to the material on a daily basis is unavoidable, but research also shows that human ingestion of aluminum oxides and aluminum hydroxide in small amount that is normally found in the environment is not hazardous. But if the materials are being continuously dispose of and in large quantity, then it may affect our drinking water or plant and eventually causes adverse effect on environment and human due to continuous exposure and in vast amount.

One of the solution that can be made so that the environment is safe, and to ensure that the supply of aluminum or its alloy are always unending and in order to reduce or eliminate the problem of disposing aluminum based material is by being green, or in other word by recycling.

1.2 Problem statement

Utilization of scrapped aluminum for re-use purpose normally will result in diminishing of its engineering properties in comparison with pure aluminum ingot. Scrapped aluminum suffered with major brittleness problem after being casted for re-usage. This scenario will affect the re-usability as well as the reliability of scrapped material to be applied in high performance automotive application. Other then impurities problem, that was being generated by the disposal of aluminum up until now, there was no major concern to further seek the potential heat treatment of the scrapped/recycled aluminum in modifying the resulted properties of the re-used aluminum cast.

It is well understood that, pure aluminum in its original form is soft, ductile and not very strong but has advantages of being light in weight, non-magnetic, high specific strength, high corrosion fatigue resistant, low specific gravity of approximately one-third of steel and high thermal and electrical conductivities, about 60% that of copper. When being treated/ cooled at different cooling rate, there will be changes occurring in the material. This variation can be well evaluated by analyzing the morphological changes on the casting sample microstructure.

For the case of scrapped aluminum metal, the cooling rate may be affected by the presence of impurities and other unwanted elements. This will further affect the resulted micro structural formation that may change the properties of the scrapped aluminum. These changes in microstructure include the dissolution of precipitates, homogenization of the cast structure, such as minimization of alloying element segregation, spheroidation and coarsening of eutectic silicon, and precipitation of finer hardening phases. Thus, the noble aim of this research is to investigate the effects of cooling rate on the mechanical and morphological properties of heat treated recycled aluminum alloy and propose the best heat treatment strategy in the form of using the best medium to control the cooling rates.

1.3 Hypothesis of research

From studies of theoretical literature and journals, hypotheses are made where:

a. Different heat treatment strategy will provide different cooling rate which affect the microstructure of the casted aluminum scrapped metal. It is expected that the faster cooling rate the finer the microstructure, thus the better the resulted physical and mechanical properties of the fabricated/produced sample.

b. It is expected that the automotive scrap provide comparable performance with the original automotive material in term of physical and mechanical properties, provide that the suitable cooling rate could be selected, correctly.

c. On brittleness of the recycled aluminum scrapped, it could be improved by applying the correct strategy of heat treatment, manipulating the potential of the different cooling rate.

1.4 Objectives of research work

To realize and determine the validity of the hypotheses, research work had been planned with the objective:

a. To determine the effect of cooling rate to the mechanical properties of the scrapped casted aluminum samples.
b. To determine the effect of cooling rate to the morphological properties of the scrapped casted aluminum samples
c. To compare the mechanical and morphological properties of aluminum recycled automotive scrap with the component before and after heat treatment.

1.5 Scope of research work

In order to realise the objective, achieving the goal as planned and hypothesized, it is essential to determine the scope of the research so that the resulting data will give the appropriate support that promotes the desired conclusion. The research will consist of:

a. Making samples by melting recycled aluminium from automotive scrap, casting and machining it to size. After heat treating the samples, the rate of cooling of the samples are controlled through the usage of different medium of water, used oil, fan air and leaving to cool naturally in the oven with the door open. The medium were selected due to the ease of obtaining and minimal cost.

b. After cooling, the samples are then tested to determine its mechanical properties through the carrying out of destructive test (DT) particularly izod impact test and tensile test which will give the value of the new samples capability to withstand impact and tensile strength before breaking. The test will also determine its elongation capability.

c. Utilization of SEM where the broken samples and also the material in its original form before melting, are cut, mounted and polished until there are no scratches on its surfaces. They are then observed on SEM for the morphological analysis to determine their structure, grain size and elements in the materials.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to aluminum alloy

According to Jacobs (1999), lump of pure aluminum that has been heated to just below the melting point and allowed to cool slowly (annealed) is light in weight, is not very strong, is soft and ductile, is corrosion resistant and has high thermal and electrical conductivities(Table 2.1). If the lump is mechanically deformed at room temperature, then it becomes noticeably harder and less ductile - the material has been "work hardened"; the mechanism of work hardening will be explained later in this section. The mechanical and physical properties of commercially pure aluminum may be also be changed by deliberate additions of other elements, for example, copper (Cu), magnesium (Mg), silicon (Si). The products have now become alloys and the aim of industrially useful alloys is to enhance their properties and hence make them more suitable for fabrication into useful products. Again, the mechanisms involved will be the subject of much discussion later in this chapter. Such alloy additions are small in amount (typically up to a few percent); consequently they have only a very small effect on the density, which remains low at typically 2800 kg.m-3. An exception is additions lithium (Li), density 540kg.m-3, of up to a few percent and specially developed for aerospace applications, where the aluminum-lithium alloy density is lower at 2200-2700 kg.m-3. Also, alloys of aluminum with small additions of lithium are stiffer than other aluminum alloys, which is a feature of benefit to some applications like aerospace product material. For the purpose of this research only alloys that are related to automotive use like aluminum silicone (Al-Si) or aluminum–silicone-copper (Al-Si-Cu) will be discussed.

Table 2.1: Annealed Pure Aluminum Properties (Jacobs, 1999)

Annealed pure aluminum is :	Typical mechanical properties are:		
		Annealed	Moderate cold work
• Not very strong	0.2% yield strength	15MPa	50MPa
• Soft and ductile	UTS	50MPa	100MPa
• Light in weight	Elongation *	50%	50%
• Corrosion resistant	Hardness	130 Hv	230 Hv
• High thermal and electrical conductivities	*Maximum elongation before breaking		

Aluminum is a lightweight material with a density of 2.7 g/cm^3 (0.1 lb/in.^{3}). Pure aluminum and its alloys have the face-centered cubic (fcc) structure, which is stable up to its melting point at 657 °C (1215 °F). Because the fcc structure contains multiple slip planes, this crystalline structure greatly contributes to the excellent formability of aluminum alloys. Aluminum is a metallic material, composed of atoms which are arranged in a specific three-dimensional array like a crystal. The way in which the atoms of all materials are bonded is determined by their atomic structure. Atoms, bonding and crystal structures most solid matter is crystalline. The atoms of which it is composed form a regular pattern which is repeated throughout space; this is the crystal structure. Since solid matter has strength, it is clear that there must be a force, the atomic bond, holding each atom to its neighbors' in the crystal. Bonding is of three basic types: Metallic bonding; Covalent bonding and Ionic bonding. Let us look at the characteristics of each in turn. In metallic bonding, an electron is lost by one type of atom and gained by another. Electrons carry a negative charge. An atom will lose one or more atoms if it has this number in its outer shell; this is the chemical definition of a metal. When metal atoms are brought together, with each having spare electrons in their outer shells then it will be sharing not one atom with another but more on a communal basis. The way a metal is best viewed is of a system of positive charges or ions (the atoms which have lost electrons are called positive ions) surrounded by a cloud of negatively-charged electrons - sometimes called 'electron-gas'. The mutual attraction between the positively charged ions and negative 'electron-gas' provides the bond.

The free electrons in the "electron gas" of a metal are relatively free to move. Under the influence of a voltage potential, an electron current flows. Hence, metals are good conductors of electricity. It is important to note that mixtures of metallic atoms occur commonly - these are known as alloys. There are many different alloys of aluminum. In all cases of metallic alloys, the simple picture of positive metal ions in an electron gas holds true. The positive metal ions may assemble into special arrays as a result of a particular heat treatment or special mechanical treatment - this gives rise to crystal structures with special features.

In the real world, very high purity aluminum is a rarity; normally aluminum material contains at least a small amount of impurities and, for most engineering applications, the material contains deliberate additions of alloying elements. The main impurities in commercially pure aluminum are iron and silicon. Iron has a